Exploring adaptation to climate variation and change: important issues and lessons to be learned in Puget Sound and the Georgia Basin.

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Abstract
This work summarizes the important issues and lesson to be learned on impact and adaptation responses to climate change in the Puget Sound and Georgia Basin. To improve predictions of climate change "impacts" on future resource use, management and conservation activities will require more effort and greater refinement of climate scenarios. As an immediate response, a second "adaptation" approach can be used to reduce risk and help capitalize on conservation and biodiversity initiatives by assuming and preparing for adverse effects of climate change; this approach defines vulnerability to climate change and develops anticipatory adaptation in management and conservation of important plants, animals and ecosystems in Canada. Adaptation to climate variability and change can be used to adjust perspectives, practices, processes, management and statutory and legal systems based on projected changes in climate. Early adaptation to climate change can assist in adjusting human and community expectations to sustainable resource use and development, and protection of habitats, ecosystems and sensitive species in the context of communities within the Puget Sound and Georgia Basin.

Introduction

Recent weather events across Canada and U.S., such as hurricanes and severe snow storms on Atlantic coast, floods in the prairies, drought, flood and fire in British Columbia and Washington, have demonstrated the dramatic influence of daily and annual shifts in the weather and its effects on our lives and communities, and the animals and plants which comprise the natural ecosystems on which we depend. Climate differs from weather. Climate is the average condition experienced across a specific set of variables like temperature, salinity, precipitation, ocean currents and wind. Long term climate is not stable and it changes over extended periods of centuries to tens of thousands of years or more, as observed in short term El Niño events or very long term changes between glacial and warming periods. The Third Assessment Report of the Intergovernmental Panel of Climate Change concludes that surface temperatures across the earth are warming at unprecedented rates associated with burning fossil fuels, forest harvesting and human development (urban, rural, industrial) on the landscape over the recent past two centuries (i.e. 1800-2000) (McCarthy et al. 2001). The rate of warming is accelerating and correlates with an increased frequency or magnitude of extreme climate events (storms, hurricanes) at levels not observed in the historic records. Human industrial development, resource extraction and land use have modified the earth's surface and have led to increased concentrations of atmospheric greenhouse gases such that global surface temperatures have increased on average 0.6 ± 0.2°C within the last century (Hengeveld 2000, Houghton et al. 2001). Global Climate Models (GCM) predict that global surface air temperature will increase on average by 1.3 to 5.8°C to 2100 relative to 1990 and that sea levels will rise 0.09 to 0.88m across the globe (Houghton et al. 2001). The Canadian Global Climate Model (CGCM) predicts that some Arctic and alpine areas a may experience greater than 5^{o}C changes in average annual temperatures, while the southern and central portions of North America will experience average temperature increases from 3-4^{o}C.

Climate change has gained global attention due to impacts on and vulnerabilities of natural systems, human society and communities, industry and resources to severe storms, drought, fires and other climate extremes. Canada along with much of the international community, has adopted the Kyoto Protocol as an approach to help mitigate and reduce greenhouse gas emissions. While mitigation will be important, it will only slow the rate of accumulation of greenhouse gases, but cannot alter the accumulated impacts or stop the progression of climate warming. In the Puget Sound and Georgia Basin (PS / GB) area of Washington

and British Columbia, it is essential that governments, agencies, researchers, industry and stakeholders understand the shared existing and future potential impacts and vulnerabilities of climate change and develop effective and appropriate methods of adapting to these impacts. Proactive adaptation through altered management, regulation, built environments (i.e. highways to hatcheries) and research can be used to help reduce the direct present and future impacts of climate change.

The unpredictable nature of climate and the predicted trends towards accelerated warming complicate the risks and opportunities faced by species, populations, ecosystems and those responsible for the management of vulnerable habitats and landscapes. This paper summarizes some of the important issues relevant to the Puget Sound and Georgia Basin region when starting to understand the context and scope of impact and adaptation responses to climate change.

Climate Impacts on Natural Ecosystems in Puget Sound and Georgia Basin

The primary topics of research over the past two decades in the PS / GB region include: natural habitats, nutrients, pathogens, freshwater and marine water quality and quantity, contaminants, toxins, stormwater runoff, invasive and exotic species, species biodiversity and populations. This broad list of issues and interests was compiled from reviews of abstracts (2003, 2005) and published literature. All these regional issues are directly influenced by climate variation and trends in climate warming and are a simple indication of the scope and extent to which potential impacts from climate variation and change will affect the region (c.f. Whitfield et al. 2003).

Climate change is expected to directly and negatively impact the spatial and temporal physical environments, habitats, landscapes, and ecosystems in which plant and animal species currently live (Dokken et al. 2002). Enhanced climate warming, variation and change predicted over the next century will impact the physical characteristics of freshwater, terrestrial and marine environments in PS / GB through degradation, loss and fragmentation of optimal habitat characteristics of many species. The general impacts of climate change on the physical environment, and on the conditions which create natural habitats, include altered:

- air and water temperatures;
- frequency of extreme weather and storm events;
- patterns of precipitation and freshwater supply;
- sea levels;
- ice cover (Arctic, coastal, freshwater)
- ocean upwelling events (El Niño, La Nina) and circulation patterns;
- ocean salinity;
- terrestrial and coastal sediment transport and erosion;
- soil moisture;
- patterns of nutrient availability
- frequency of catastrophic events.

Climate change is expected to impact the biological extent and characteristics of plants and animals and influence individuals, species, and populations to scales of ecosystems through altered:

- spatial distribution, range, and migration of individual species;
- growth and physiology of individuals within a population;
- timing match – mismatches with a species life history;
- diversity of prey, predators and competitors within communities;
- species composition and distribution within ecosystems;
- migration and movement corridors;
- exotic and invasive species introductions and distribution;
- parasite and disease risks.

Climate change is linked to the survival and success of a population of a species or an entire community through biological mechanisms which: (a) directly impact the habitat characteristics and interactions in an ecosystem of a species or (b) indirectly impact the foodwebs or community structures in which individual species currently live. Direct impacts alter optimal habitat suitability of a species by influencing the level of stress or exceeding tolerances to environmental variables like temperature, moisture, sunlight, current (ocean, stream), contaminants etc. Indirect impacts alter the availability of food and nutrients, abundance

and characteristics of predators and competitors, including invasive and exotic species, and vulnerability to disease, parasites and resilience to toxins.

Climate Variation and Change in Puget Sound and Georgia Basin

A preliminary gap analysis of the state of knowledge on climate change in Puget Sound, Georgia Basin and the Strait of Georgia was based on a systematic search and database compilation of available literature in the region. The regional database currently includes 101 records compiled using key words and search phrases including: climate, climate change, resources, impacts, and adaptation. The database is not exhaustive, but provides a representative review of the literature.

Our review produced the following results.

- Review of the 101 records related to climate or climate change in the PS / GB region. These records represented research across physical, biochemical, biological impacts (92) and adaptation (9) responses to climate change including broad overview discussions, case studies and retrospective empirical analyses;
- 22 records dealt with impacts on salmon populations;
- 18 records on water quality and quantity impacts;
- 10 records on marine plankton distribution and production and foodweb interactions and impacts;
- 8 records on sediment cores and broad trends in climate over time;
- 8 records on physical – chemical distribution and trends including nutrients, salanity and temperature;
- 6 records dealt with impacts on marine fish and fisheries;
- 5 records on overview impacts;
- 4 records on climate impacts on paralytic shellfish poisoning;
- 4 records on intertidal communities, eelgrass and shellfish impacts;
- 4 records dealt with impacts on marine mammals and bird populations;
- 3 records on impacts invasive and exotic species;
- 9 records on adaptation studies on salmon, water quantity, invasive species and overview issues.

These results identify the time trend of research conducted in the region. Figure 1 presents cumulative research records over time divided among impact and adaptation studies including: (a) biological and species relevant issues, (b) salmon and fisheries, (c) water quantity and quality and (d) adaptation research studies. The time trends demonstrates a progression toward more integrated research across multiple disciplines. These results also highlight the distinction between impacts and adaptation research studies, confirm the lack of adaptation research, and point out the need to develop more adaptation research studies in the region. I found no studies which specifically reviewed case studies by geographic or topic area for both impact and adaptation responses to climate change in the PS / GB region. Little emphasis has been placed on impact, vulnerability or adaptation responses focused on socioeconomic or built environment interactions of climate change and fisheries systems.

Adaptation in Conserving and Protecting Natural Ecosystems, Biodiversity and Habitats in Puget Sound and Georgia Basin

The final report on climate change from the Canada's Standing Senate Committee on Agriculture and Forestry (2003) concludes that mitigation and adaptation must be complimentary activities used by communities, industry sectors and agencies to effectively cope with a changing climate. Mitigation of greenhouse gas emissions alone cannot stop climate change; it can only slow the rate of change. A conscious response to climate change through planned adaptation can result in directed decisions and adjustments in ecological, social, economic and statutory systems in response to the impacts and perceived risks of climate change (Smit & Pilifosova 2003). Adaptation refers to actions or adjustments in practices, processes, or structures taken in response to actual or anticipated changes in climate to reduce negative

impacts and to take advantage of new economic opportunities (Smit et al. 2000, Smit & Pilifosova 2001). Adaptation can be implemented at local, regional, national and global scales and may involve technological, institutional and social behaviour change over short or long periods.

Evidence suggests that the influence of climate change on Canada's vulnerable habitats, biodiversity and species at risk in marine, freshwater and terrestrial systems over the next century will be significant and widespread. Anthropogenic climate change and warming ranks alongside other recognized threats to global biodiversity and habitat conditions and availability. Research must be used to understand ecosystem, habitat, population and species responses to climate variation and change and lead to increased dialogue between scientists, policy makers and managers to improve and develop adaptive decision making and the effectiveness of research. These results suggest that the management and conservation of the region's plant and animal biodiversity, vulnerable habitats, species and human settlements should involve adaptation to climate change to:

- raise awareness and understanding of climate change issues;
- reduce present and future risks by preparing for adverse effects;
- provide opportunities to capitalize on positive effects; and
- provide greater flexibility and integrated decision making for the resource and human development, land protection and conservation to respond to unpredicted residual impacts of climate change.

Climate change adaptation strategies should become an integral component of effective local, regional and national planning, management and operation in conservation and protection of habitats and natural systems through: (a) planned adaptation to define ecological rationale and management (i.e. stormwater management, habitat restoration), land use for parks, protected areas, refuges, reserves and resource extraction and development, and the mix of cultural, socio-economic and ecological attributes in the planning and management process, and (b) sustainable management for biodiversity through a balance of land use activities and biodiversity goals, risk management for economic development, conservation and biodiversity, and strategic planning to develop alternate views and context for sustainable resource use and reduced vulnerability of natural systems. What is suggested is that climate change will accelerate over the next century leading to unpredicted weather and climate related extremes or events which may reduce or eliminate current vulnerable habitats and subsequently threatened species. Including adaptation in management and decision making for biodiversity, habitats and species at risk requires an integrated view of the physical and biological ecosystems in association with human social, economic and infrastructure and built environments. Future avenues of research and management of climate change and its potential impacts on the condition of ecosystems, landscape in the Puget Sound and Georgia Basin should progress through a framework to:

- promote enhanced awareness and understanding,
- build research in this field to explore and fill knowledge gaps;
- link researchers with stakeholders to provide answers about impacts;
- work with the industry, researcher, agencies and communities to explore present and future effective adaptation options; and
- work with agencies, industry and communities to monitor and manage to reduce vulnerability to future climate change through research and innovation.

Additional information and links on climate change and fisheries and aquatic science issues can be found on www.fishclimate.ca (Canadian Climate Impact and Adaptation Research Network – Fisheries and Aquatic Sciences Sector) and the national network site at www.c-ciarn.ca.

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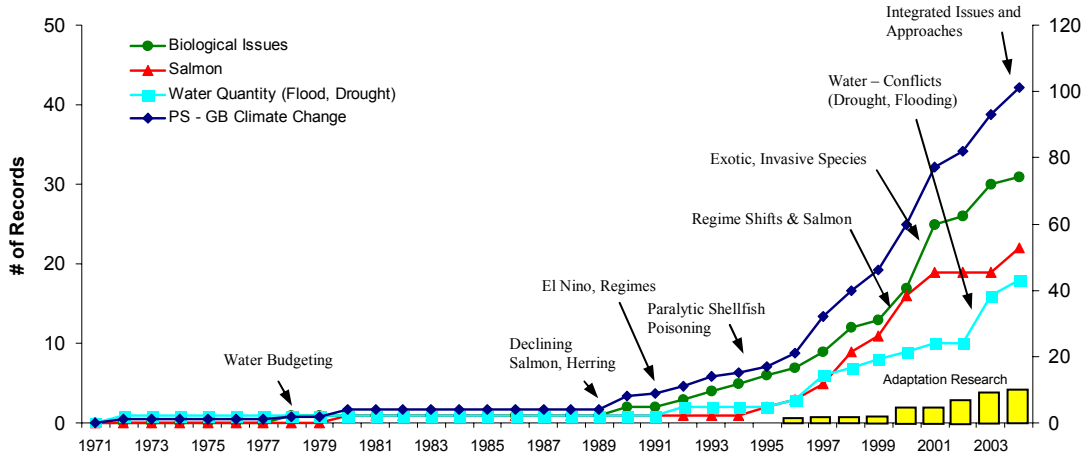

Figure 1: Numbers of records over time on impact and adaptation responses to climate change in the Puget Sound / Georgia Basin.